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SUMMARY

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DEPARTMENT OF THE INTERIOR
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CONTENTS

INTRODUCTION

This Annual Report is the sixth of a series describing the results of research conducted by the U.S. Geological Survey on behalf of the National Aeronautics and Space Administration under contract R-66. This report, prepared by the Astrogeologic Studies Section of the Branch of Astrogeology, covers the period July 1, 1964 to July 1, 1965, and is in three volumes corresponding to three areas of research: Part A, Lunar and Planetary Investigations; Part B, Crater and Solid State Investigations; and Part C, Cosmic Chemistry and Petrology; and a map supplement. An additional volume presents summaries of the papers in Parts A, B, and C.

Long-range objectives of the astrogeologic studies part of the program are to determine and map the stratigraphy and structure of the Moon's crust, to work out from these the sequence of events that led to the present condition of the Moon's surface, and to determine the processes by which these events took place. Work being carried out that leads toward these objectives includes a program of lunar geologic mapping; studies on the discrimination of geologic materials on the lunar surface by their photometric, polarimetric, and infrared properties; field studies of structures of impact, explosive, and volcanic origin; laboratory studies on the behavior of rocks and minerals subjected to shock; and study of the chemical, petrographic and physical properties of materials of possible lunar origin and the development of special techniques for their analysis.

PART A, Lunar and Planetary Investigations (with the map supplement), contains the preliminary results of detailed geologic mapping of 15 new quadrangles at a scale of 1:1,000,000. The equatorial belt of the Moon (32°N-32°S, 70°E-70°W) has now been completely mapped in this fashion. Significant results of new mapping of both volcanic and impact features and detailed studies of previously defined stratigraphic units are included. Systematic photometric, polarimetric, and infrared studies designed to assist in the geologic mapping are discussed, and a proposed method of improving selenodetic control by laser radar ranging is described.

Studies of the geology and surface properties of the Moon at scales larger than the 1:1,000,000 scale used for reconnaissance geologic mapping have been made with photographs from the three successful Ranger missions. The results of these investigations are being described in a series of Technical Reports published by the Jet Propulsion Laboratory for the National Aeronautics and Space Administration. A summary of this work is included in the section on lunar and planetary investigations.

PART B, Crater Investigations, contains the results of field and laboratory studies of crater phenomenology, including volcanic, explosives and impact events. Investigations of naturally formed terrestrial craters from three localities are: (1) the Henbury meteorite craters in Australia, (2) the Sierra Madera structure in west Texas, and (3) the Flynn Creek structure in Tennessee. Another report discusses the distribution of mercury in shocked and unshocked rocks at the Odessa meteorite craters near Odessa, Texas, and another report discusses the possible origin of pseudotachylite from Archean granite of the Vredefort dome in South Africa.

Two experimental impact studies are: (1) a study of impact craters formed in water-saturated sediments by impacting missiles, and (2) a study of the fragmentation of colliding spheres of basalt. Another report discusses the geology of a part of a large body of granite in central Colorado that is being considered as a site for high-explosive cratering experiments in hard, polymineralic rocks.

One report discusses the geology of the Moses Rock diatreme in San Juan County, Utah, and its similarity to rilles on the lunar surface.

PART C, Cosmic Chemistry and Petrology, includes reports dealing with the techniques of study, the analysis, and the interpretation of data on materials of known or suspected extraterrestrial origin. The following are reported: a study jointly supported by the Geochemical Census Branch of the Geological Survey of the statistical treatment of superior analyses of tektites and the petrologic interpretation of the results; a study jointly supported by the Southwest States Branch of the Geological Survey of the petrologic significance of tektite analyses; minor-element data for basaltic meteorites are reported; and a theoretical and experimental study of the stability of meteoritic cohenite as a function of temperature and pressure. The cosmic dust investigations, supported by the National Aeronautics and Space Administration and other government agencies, contributes a report on the application of the scanning electron microscope and a progress report on the construction of laboratory facilities.

The following reports were published during the reporting period July 1, 1964 to July 1, 1965:

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Cummings, David, 1965, Kink-bands--Shock deformation of biotite resulting from a nuclear explosion: Science, v. 148, no. 3672, p. 950-952.

DeCarli, P. S., and Milton, D. J., 1965, Stishovite--Synthesis by shock wave: Science, v. 147, no. 3654, p. 144-145.

Duke, M. B., 1965, Metallic copper in stony meteorites [abs.], in Abstracts for 1964: Geol. Soc. America Spec. Paper 82, p. 50.

______ Metallic iron in basaltic achondrites: Jour. Geophys. Research, v. 70, no. 6, p. 1523-1527.

Duke, M. B., and Brett, Robin, 1965, Metallic copper in stony meteorites: U.S. Geol. Survey Prof. Paper 525-B, p. B101-B103.

Fahey, J. J., 1964, Recovery of coesite and stishovite from Coconino Sandstone of Meteor Crater, Arizona: Am. Mineralogist, v. 49, no. 11-12, p. 1643-1647.

Gault, D. E., and Moore, H. J., 1965, Scaling relationships for microscale to megascale impact craters: Hypervelocity Impact Symposium, 7th, Tampa, Fla., 1964, Proc., v. 6, p. 341-351.

Hackman, R. J., 1964, A lunar isotonal map: Photogrammetric Eng., v. 30, no. 6, p. 1011-1016.

Hamilton, Warren, and Wilshire, H. G., 1965, Liquid fractionation of basaltic magma [abs.], in Abstracts for 1964: Geol. Soc. America Spec. Paper 82, p. 331.

Hoyt, A. F., Senftle, Frank, and Wirtz, P., 1965, Electrical resistivity and viscosity of tektite glass: Jour. Geophys. Research, v. 70, no. 8, p. 1985-1994.

McCauley, J. F., 1965, Slope frequency distribution as a means of classifying lunar terrain [abs.], in Abstracts for 1964: Geol. Soc. America Spec. Paper 82, p. 130.

Mead, C. W., Littler, Janet, and Chao, E. C. T., 1965, Metallic spheroids from Meteor Crater: Am. Mineralogist, v. 50, no. 5/6, p. 667-681.

Milton, D. J., 1964, Fused rock from Köfels, Tyrol: Tschermaks Mineralog. Petrog. Mitt., ser. 3, v. 9, no. 1-2, p. 86-94.

______ 1965, Alleged meteorite crater on Soqotra: British Astron. Assoc. Jour., v. 75, no. 4, p. 283.

______ Structure of the Henbury meteorite craters, Australia [abs.], in Abstracts for 1964: Geol. Soc. America Spec. Paper 82, p. 266.

Moore, H. J., Gault, D. E., and Heitowit, E. D., 1965, Change of effective target strength with increasing size of hypervelocity impact craters: Hypervelocity Impact Symposium, 7th, Tampa, Fla., 1964, Proc., v. 4, p. 35-45.

O'Connor, J. T., 1965, A classification for quartz-rich igneous rocks based on feldspar ratios: U.S. Geol. Survey Prof. Paper 525-B, p. B79-B84.

Rose, H. J., Jr., and Cuttitta, Frank, 1965, Microanalysis by X-ray fluorescence--Determination of selected major constituents in silicates [abs.], in Abstracts for 1964: Geol. Soc. America Spec. Paper 82, p. 166.

Rose, H. J., Jr., Cuttitta, Frank, and Larson, R. R., 1965, Use of X-ray fluorescence in determination of selected major constituents in silicates: U.S. Geol. Survey Prof. Paper 525-B, p. B155-B159.

Rowan, L. C., and Larsen, L. H., 1965, Structural analysis of the Quad Creek, Wyoming Creek, amd Line Creek area, Beartooth Mountains, Montana and Wyoming [abs.], in Abstracts for 1964: Geol. Soc. America Spec. Paper 82, p. 169.

Shoemaker, E. M., 1964, The geology of the Moon: Sci. Am., v. 211, no. 6, p. 38-47.

Shoemaker, E. M., 1964, The Moon close up: Natl. Geographic, v. 126, no. 5, p. 690-707.

______ 1965, Preliminary analysis of the fine structure of the lunar surface in Mare Cognitum, in Ranger VII, pt. 2, Experimenters analyses and interpretations: California Inst. Technology, Jet Propulsion Lab. Tech. Rept. no. 32-700, p. 75-134.

Taylor, H. P., Duke, M. B., Silver, L. T., and Epstein, Samuel, 1965, Oxygen isotope studies of minerals in stony meteorites: Geochim. et Cosmochim. Acta, v. 29, p. 489-512.

Walter, L. S., and Carron, M. K., 1964, Vapor pressure and vapor fractionation of tektite melts: U.S. Natl. Aeronautics and Space Adm. Tech. Note D-1084, 13 p.

Summary of Part A

Lunar investigations are based on geologic mapping of the Moon at a scale of 1:1,000,000. The lunar equatorial belt, 70°W-70°E and 32°N-32°S, has been completely mapped. Geologic maps of the Kepler, Letronne, Riphaeus Mountains (Montes Riphaeus), and Timocharis quadrangles have been published in color (fig. 1.). Colored maps of the Aristarchus, Montes Apenninus, Pitatus, and Mare Humorum quadrangles are in press or final preparation. Preliminary uncolored maps of the Hevelius, Copernicus, Mare Vaporum, Grimaldi, and Theophilus quadrangles, as well as of the quadrangles in press, have been transmitted to the National Aeronautics and Space Administration previously. Preliminary uncolored maps accompanying this report are: Seleucus, by H. J. Moore; Mare Serenitatis, by M. H. Carr; Macrobius, by H. A. Pohn; Cleomedes, by A. B. Binder; Julius Caesar, by E. C. Morris and D. E. Wilhelms; Taruntius, by D. E. Wilhelms; Mare Undarum, by Harold Masursky; Ptolemaeus, by Harold Masursky; Colombo, by D. P. Elston; Langrenus, by J. D. Ryan and D. E. Wilhelms; Byrgius, by N. J. Trask; Purbach, by H. E. Holt; Rupes Altai, by L. C. Rowan; Fracastorius, by D. P. Elston; and Petavius, by D. E. Wilhelms.

The 28 maps forwarded to date cover more than three million square miles. By the end of fiscal year 1966, preliminary uncolored maps of eight additional quadrangles, outside the equatorial belt, will have been completed, and many of the maps now in preliminary form will have been published in color.

A preliminary map of the Byrgius quadrangle by N. J. Trask suggests that ejecta from both the Mare Orientale and Mare Humorum basins are present. Much of the area between the two basins is composed of highly pitted material and patches of level upland filling material. The pitted terrain may represent fields of secondary impact craters formed by material ejected from the Mare Orientale and Mare Humorum basins. Lineaments are widespread in the quadrangle; most are oriented northwest-southeast.

H. A. Pohn has described a low-lying area marginal to the northeast edge of the Serenitatis basin in the Macrobius quadrangle and named it the Serenitatis bench. The most widespread deposit on the bench is the Bond Formation, a new unit, which is flat overall but heavily cratered and dissected by rilles. It postdates the formation of the Serenitatis basin and predates the deposition of the mare material of the Procellarum Group. The Bond Formation appears to be an early generation of mare material. The Serenitatis bench and the Bond Formation of the Serenitatis basin are analagous to the Apennine bench and the Apennine Bench Formation of the Imbrium basin.

The previously recognized hummocky and smooth facies of the Fra Mauro Formation, a widespread and well-defined map unit surrounding the Imbrium basin, have been mapped in the Mare Vaporum quadrangle by D. E. Wilhelms and in the Julius Caesar quadrangle by E. C. Morris and D. E. Wilhelms. In addition, Wilhelms recognizes a pitted facies, and proposes a restricted definition of the smooth facies. Some material previously considered part of the smooth facies is withdrawn from the Fra Mauro Formation and assigned to a new unit, the Cayley Formation, in an attempt to clarify the relations and genesis of the materials in the vicinity of the Mare Imbrium basin. The sequence of the Fra Mauro facies from the northwest to the southeast is similar to the sequence of facies of crater rim materials from the rim crest radially outward from craters. Previous interpretations of both the Fra Mauro and the crater rim material as impact ejecta are supported by this study. The Cayley Formation is interpreted as mare-like material older than the Procellarum Group.

M. H. Carr describes several probable volcanic units in the north-central part of the Moon. Most of these units are associated with rilles, and all have very low albedos. Within Mare Serenitatis, around the Littrow and Menelaus rilles, are dark units that terminate abruptly against the uplands and have scarplike contacts with the Procellarum Group. These two units are thought to be composed of volcanic flows that are younger than the rest of the mare material. Near the Sulpicius Gallus rille and in an area 150 km southeast of the crater Copernicus, dark materials with no intrinsic relief overlie both the Fra Mauro Formation and the Procellarum Group. These dark materials are

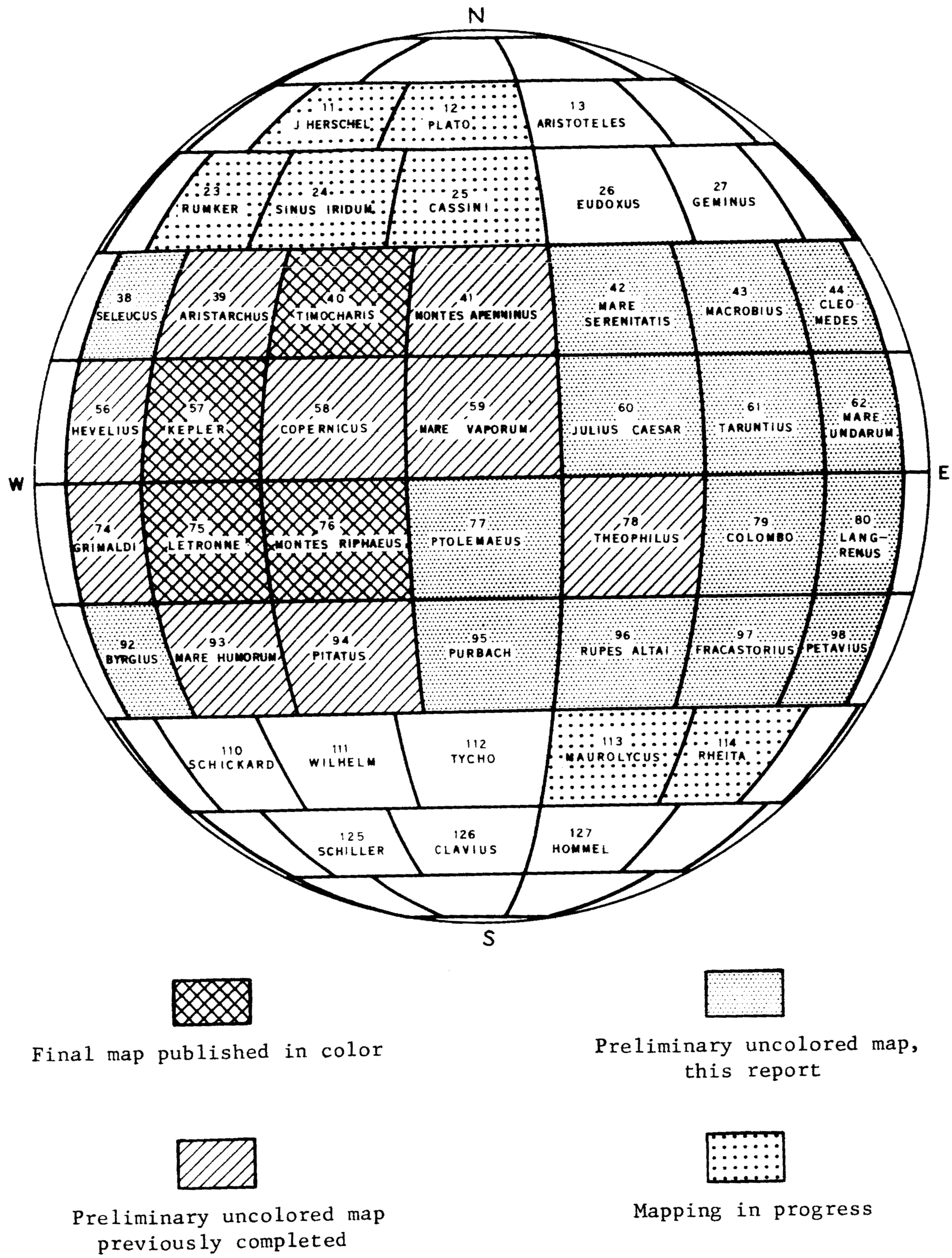

Fig. 1.--Index map of Moon showing status of geologic mapping at a scale of 1:1,000,000.

interpreted as pyroclastic volcanics, and are also younger than the mare material. Other probable pyroclastic deposits occur around Sinus Aestuum and Mare Vaporum, but these are older than the local mare surface.

The Marius Hills volcanic complex, a broad, smooth plateau with many closely spaced domes in the western part of the Oceanus Procellarum, has been described by J. F. McCauley. The complex embraces about 35,000 km^2 and rises several hundred meters above the surface of the mare. The many domes are from 3 to 10 km wide and from 200 to 1,000 meters high. Two types of domes have been recognized: broad, low domes of the type common in the lunar maria and less abundant, steep-sided domes with rille-like structures on their flanks. Many of the domes have small summit pits. The Marius Hills complex has a markedly lower density of craters than an area of comparable size directly to the east in Oceanus Procellarum, which it appears to postdate. It is in turn overlain by faint rays from the Copernican craters Kepler and Aristarchus and has, therefore, been given a tentative Eratosthenian age designation. The complex may represent a succession of post-Imbrian volcanics with the two types of domes possibly formed by magmas of different composition.

Completion of preliminary geologic mapping of the eastern part of the lunar equatorial belt by D. E. Wilhelms, Harold Masursky, A. B. Binder, and J. D. Ryan, makes possible revised interpretations of the structural evolution of large craters and mare basins. Both Mare Crisium, a small mare basin with relatively few craters on its rim, and Petavius, the largest essentially unmodified crater of the lunar equatorial belt, have steep-sided depressions on the outer periphery of their rims. The walls of these depressions are parallel to the directions of the lunar grid. Subsidence of the concentric trough around Mare Crisium probably occurred along these grid faults. Cross faults cutting the concentric troughs and ridges around most other mare basins also follow lunar grid directions rather than directions radial to the basins. A broad graben along much of the rim crest of Petavius may be a scaled-down representative of the shelves on the inner margins of several mare basins such as Imbrium, Humorum and Crisium. The shelves resemble this graben more closely than they do the terraces formed by inward slumping in smaller craters. The area also includes Langrenus, the largest known Copernican crater, upon whose rim flank is the largest known dark-halo crater. This dark-halo crater and other dark parts of the rim material may be the products of volcanic activity concentrated along lunar grid faults activated by the Langrenus impact.

The geology of the lunar equatorial belt (70°W-70°E, 32°N-32°S) has been compiled at a scale of 1:5,000,000 by D. E. Wilhelms and N. J. Trask from 1:1,000,000 maps made by members of the Branch of Astrogeology. The history of mare basins can be worked out in terms of the stratigraphic units in and around the basins; units older than, contemporaneous with, and younger than, the basin are shown on the map. The units on the map recognized as older than the basins are crater materials and undifferentiated regional materials; possible contemporaneous units are chiefly the basin rim materials; younger units are crater materials and regional plains-forming materials of the terrae and maria. In addition, local units of possible volcanic origin, not related to basin history, are shown. The tentative order of basin formation, youngest to oldest, is: Orientale, Imbrium, Crisium, Humorum, Nectaris, Serenitatis, Fecunditatis.

The history of a circular crater in a highly viscous medium is derived from the hydrodynamic equations of motion by Z. F. Daneš. The variation in shape of the crater in the course of time is expressed as a function of a time constant, T, that involves viscosity and density of the medium, acceleration of gravity and radius of the crater lip. Correspondence between theoretical crater shapes and the observed ones is good. However, the time constant, T, is surprisingly short if commonly accepted viscosity values are used. Thus, if the present analysis is valid, and lunar crater ages are of the order of 10^9 years, lunar rock viscosities must be of the order of 10^{25} to 10^{26} poise. If viscosities of lunar rocks were around 10^{21} to 10^{22} poise, the ages of large craters would have to be only 10^4 to 10^7 years.

D. E. Wilhelms and N. J. Trask have studied the polarization properties of 20 regions on the lunar surface involving 10 currently recognized geologic units by telescopic measurements with a Lyot polarimeter. They find that the value of maximum polarization differs considerably among these units and can aid in their discrimination. For units with widely differing albedos, maximum polarization and albedo are inversely related. Among some mare units with a relatively small spread in albedo, the polarization of some of the darker units appears to be anomalously lower than that of some of the brighter units.

L. C. Rowan and M. N. West have prepared a map showing the albedo variations in the lunar equatorial belt (20°N-20°S, 60°W-60°E). Units of albedo corresponding to density on a full-moon photographic plate were established by a photographic technique. Film negatives, each showing a progressively higher albedo unit, were projected onto an enlarged photograph of the same full-moon plate, and areas of equal albedo were outlined. The resulting information was adjusted to a 1:5,000,000 scale orthographic projection chart and has been used in the preparation of some 1:1,000,000 lunar geologic maps.

Robert Wildey has studied and affirmed the feasibility of using laser ranging techniques to measure the shape of the Moon and a plan of investigation has been evolved. Laser technology does not permit bursts larger than 10 joules at 1-second intervals, so that measuring times per range point of 5-10 minutes, or longer when very near the limb, are necessary to obtain 50- to 100-meter accuracy in the reduced radius vector. Uncertainties in the Moon's range and vibration and libration ephemeris are small enough to permit nominal spherical curvature to be used in the metric tensor describing the wandering of the range point over the lunar surface away from a preselected target. Therefore, the effect can be corrected out of the data in deriving the lunar figure.

Previous explanations by Pettit and Nicholson of their 1930 infrared observations imply significantly steeper slopes at a scale of 1 km than exist on the Moon. Kenneth Watson suggested last year that one possible explanation of both the full-moon and subsolar infrared observations is the existence of surface roughness on a scale between 1 cm and 1 meter. During this past year he constructed theoretical sloped models of the surface and computed the infrared emission assuming that the individual surface elements were Lambertian. A reasonable fit to Pettit and

Nicholson's full-moon observation was obtained for a mean slope of 18°. Extrapolation of terrestrial observations and Ranger studies of lunar surface roughness versus scale suggests that the computed mean slope corresponds to a slope length between 1 and 10 cm. Future broad-band infrared emission studies from the Manned Lunar Orbiter will provide useful textural detail two orders of magnitude better than photographs in visible wavelengths.

Photographic photometry, although inherently subject to errors much larger than those in photoelectric photometry, can in no case be carried out without some kind of calibration of the dependence of photographic density on exposure (brightness at exposure time). Many older plates are photometrically valueless because of the lack of such calibration. By taking density readings of selected spots on an old plate and also making photoelectric measurements through the telescope of these same spots when the moon nearly duplicates the phase and libration corresponding to the epoch of the old plate, the calibration can be regained. The technique is discussed by H. A. Pohn and R. L. Wildey. It is assumed that there are no secular effects in the moon's reflectivity and that lack of knowledge of the spectral sensitivity of the old plate is not an important factor. In addition, by using many lunar spots, one can measure, and even provide limited compensation for, photometric nonuniformity of the original plate.

Summary of Ranger investigations.--Members of the Astrogeologic Studies section of the Branch of Astrogeology have used photographs from the three successful Ranger missions, VII, VIII, and IX, to study the geology and surface properties of the Moon at scales larger than the 1:1,000,000 scale used for reconnaissance geologic mapping. The results of these investigations are being described in a series of Technical Reports published by the Jet Propulsion Laboratory for the National Aeronautics and Space Administration. A brief summary of these investigations is presented here.

The Ranger VII spacecraft transmitted to earth close-up pictures of a ray-covered mare area in August 1964. These pictures were analyzed by E. M. Shoemaker and reported on in NASA Technical Report No. 32-700, which also includes reports by the other Ranger experimenters. This report describes in detail the features observed on the photographs. Craters with a great variety of shapes are the dominant topographic elements on all of the photographs; positive relief features are exceedingly rare. The smallest resolvable craters have diameters of 1 meter, approximately 1000 times smaller than can be seen with earth-based observations. Shoemaker interprets most of the craters as produced by impact. He calculates the frequency of secondary craters to be expected from the measured density of large primary craters and concludes that most of the craters observed on the photographs are secondaries. He furthermore observes that the frequency of craters less than approximately 100 meters in diameter is considerably less than predicted, suggesting that many craters have been destroyed by ballistic erosion and the formation of later craters. The possibility that repeated cratering of a surface would lead to a steady-state condition in which the crater frequency remained the same for craters below a given size was suggested earlier by Moore.

The Ranger VIII spacecraft transmitted pictures of an area in Mare Tranquillitatis in February 1965 and the Ranger IX spacecraft transmitted pictures of the floor of the large crater Alphonsus one month later. Results of preliminary analysis of both the Ranger VIII and Ranger IX photographs will be combined in a single Technical Report now in preparation. Various aspects of the photographs have been considered by different investigators.

N. J. Trask has made a study of the size-frequency distribution of the craters on all three sets of Ranger photography. He finds that, within reasonable limits, the frequencies of craters below approximately 100 meters in diameter are the same on the three surfaces. The floor of Alphonsus is closely similar to geologic units that are clearly older than the mare surfaces and is probably older than the maria themselves. The similarity of crater frequencies on surfaces of differing ages is consistent with the idea that repeated cratering has produced a steady-state surface on which crater frequencies do not change with time for craters below a given size. A very rapid increase in the number of craters with diameters between 3 and 1 km is observed on both the Ranger photographs and superior earth-based photographs. The increase is thought to be due to the addition of large numbers of secondary craters to the total crater population.

H. J. Moore has compared the smallest craters photographed on the last frames of Ranger IX with craters of the same size produced by chemical and nuclear explosives and missile impacts in natural materials. If the majority of lunar craters are formed by impact, the comparison suggests that the lunar surface materials are weakly cohesive to noncohesive. There are no large, sharply defined blocks around the lunar craters such as occur in profusion around chemical explosion craters in such materials as basalt. There are a few low, lumpy structures on the walls and rims of the lunar craters; these are similar to isolated low lumps found around craters formed by missile impacts into weakly cohesive material. Scalloped rims and asymmetric rim deposits are also found in both lunar craters and artificial craters formed in weakly cohesive materials. The slopes of the walls of all the lunar craters appear to be less than 38° in contrast to slopes of 60° in the walls of craters in weakly cohesive alluvium. The low slopes of the lunar craters are consistent with a surface layer of noncohesive, fragmental material lying at its natural angle of repose.

A study of the structure and texture of the floor of Alphonsus has been made by M. H. Carr. He discriminates five geologic units, largely on the basis of characteristic size-frequency distributions of craters. Many of the craters are aligned along lineaments and are clearly of internal origin. Dark-halo craters occurring along lineaments appear to be examples of volcanic craters with a surrounding blanket of pyroclastics. Other crater deposits as well as blanket deposits on the floor are interpreted as volcanic ejecta. Lineaments are widespread on the floor and correspond to the directions of the lunar grid and to the direction radial to the Mare Imbrium basin. The distribution of the lineaments is not the same at all scales, however.

An experimental topographic map of a small area in Mare Tranquillitatis has been constructed by H. J. Moore and R. V. Lugn. They used diapositive plates of the next-to-last and third-from-last A frames of Ranger VIII, two frames that give good stereoscopic coverage, and a slightly modified ER55 plotting instrument. The relative positions of the spacecraft camera at the times of recording the two images, the inclinations of the camera axis, and the angle of view of the camera were reproduced in the plotting instrument by proper positioning of the projectors and proper choice of diapositive size. The resulting stereo model was "soft" and "fuzzy" but could be contoured with generally the same results by independent operators. On this model, the mare surface appears to be nearly level, on the average, with local gentle slopes near 7°. The slope of a well-defined large shadow in the model was measured to be 14° ± 2°, in agreement with the local elevation of the sun at the time of the Ranger VIII impact.

A series of geologic maps has been constructed from the Ranger VIII and IX photographs at a variety of scales. D. J. Milton and D. E. Wilhelms have used a relatively distant Ranger VIII photograph to prepare a map at a scale of approximately 1:500,000 that shows in greater detail the distribution of the regional units mapped earlier at scales of 1:1,000,000. J. F. McCauley mapped the floor of the large crater Alphonsus at a scale of approximately 1:100,000. The additional detail that can be mapped at this larger scale requires the definition of new stratigraphic units not resolvable on the 1:1,000,000 scale maps. A geologic map of the small area in Mare Tranquillitatis covered by the topographic map of Moore and Lugn was constructed by N. J. Trask. He plotted the geology directly from the stereo model of the lunar surface produced by the ER55 plotter. All of the geologic units recognized on the mare surface at this scale are subdivisions of craters. H. H. Schmitt used the final B camera frame of Ranger VIII to prepare a detailed map of crater units at a scale of approximately 1:10,000. He then used the map to plan two hypothetical traverses by astronauts from a landed LEM. The traverses were designed to enable the astronauts to sample a diversity of crater materials and to examine a variety of structures observable on the ground.

Summary of Part B

Detailed mapping of Sierra Madera, a nearly circular structure of possible impact origin in west Texas, was extended by H. G. Wilshire to the ridge north of that mapped by Shoemaker and Eggleton (1964). All of the formations mapped, from the Permian Gilliam to the Cretaceous Edwards, are severely deformed. The principal structures mapped are steep normal (?) and reverse faults that trend nearly at right angles to the transverse faults mapped by Shoemaker and Eggleton, and thrust faults that resulted in movement of Permian rocks away from the center of the structure and over the Cretaceous rocks.

A comparison of lithologies of Permian formations in the northeastern Glass Mountains with those of the same formations at Sierra Madera revealed several facies changes, the most important being an increase in abundance of sedimentary breccia at Sierra Madera. New paleontologic data on cuttings from the Phillips no. 1 Elsinore well indicate that the well penetrated brecciated rocks of the Word Formation overlying a near-normal thickness of partly brecciated rocks of the Leonard Formation.

D. J. Milton has continued his study of the meteorite craters at Henbury, Australia. His earlier work with F. C. Michel described one of the smaller craters in the field, a crater with rays of ejecta similar to those around lunar craters. The latest work deals mainly with the great variety of structures in the walls and rims of the three larger craters. Beds originally dipping into the main crater were deformed into concentric folds overturned outward with generally steeply dipping axial planes. Some thrust faulting accompanied the folding, and in places an imbricate series of thrust sheets was shoved over the precrater surface on the rim. Beds on the opposite wall of the main crater, which originally dipped away from the crater, were deformed into a series of folds with shallowly dipping axial planes. An overturned flap is present on the outer rim of the crater on the side on which the beds dip outward; part of the flap is thrust outward as well as overturned. There is, in general, structural continuity between the crater walls and rims. Outside the rim crests, the ejected materials become increasingly broken, but there is rarely a clear line between coherently deformed rock and throwout debris.

Detailed geologic mapping of the Flynn Creek structure at 1:6,000 in an area of about 21 square miles is approximately 75 percent complete. An additional area mapped at 1:12,000 surrounding the 1:6,000 map area is approximately 50 percent complete. These two geologic maps, covering both the detailed and regional geology in an area 6 miles square surrounding the Flynn Creek structure, will be completed by David J. Roddy by the latter part of 1966.

The field data have shown that after the structure was formed, the topography was eroded to a region of very low relief consisting of hills from a few meters to a maximum of 20 meters high. Erosion removed all debris from the rim but did not fill the crater; later deposition of the Chattanooga Shale during Late Devonian time then filled the crater and covered the surrounding area.

No trace-element anomalies, abnormal mineral variations, or high-pressure polymorphs have been found in laboratory studies. Petrofabric studies of the deformed rim rocks show that the number of twin lamellae and microfracturing parallel to the cleavage increase toward the crater.

The major structural elements are shown in four generalized cross sections. Two major rim folds with vertical axial planes concentric to the crater rim suggest strong horizontal compression at shallow depths during formation of the structure.

The geology of the Moses Rock intrusion, a dikelike body of kimberlite 4 miles long, is being studied by Thomas R. McGetchin. The kimberlite contains many fragments of the basement rock and overlying sedimentary rocks. Other inclusions, such as pyroxenite and eclogite, may have been derived from the mantle. The original surface expression of the intrusion was probably similar to lunar rilles that contain crater chains.

Pseudotachylite occurs in net veins in the Archean granite core of the Vredefort dome. H. G. Wilshire reports that the microscopic fabric of the pseudotachylite and its inclusions indicates that little, if any, fusion has taken place, and that shearing was probably a dominant factor in the rounding and comminution of rock fragments. The survival of perthite derived from the granite indicates that the prevailing temperature during formation of the pseudotachylite was less than about 650° C.

Rock bursting into dilated zones caused by movement along irregular fault planes is postulated as a cause of formation of breccias in which the pseudotachylite is found; further movement in and along the breccia zones caused mylonitization of the rock and injection of mylonite into fractures separating the rock fragments.

H. G. Wilshire, J. T. O'Connor, and G. A. Swann studied and mapped the geology of the Twin Lakes batholith, Lake and Chaffee Counties, Colorado. The northern part of the batholith is composed of porphyritic quartz monzonite that was emplaced in Precambrian metamorphic and igneous rocks. An abundance of large orthoclase phenocrysts, commonly 3 to 5 inches long, serves to distinguish this rock from other granitic intrusions in the region. In marginal parts of the batholith, orthoclase phenocrysts are commonly concentrated in lenses; thin layers enriched in mafic minerals occur in the same areas and define a locally pronounced flow foliation. The batholith is cut by north- and northeast-trending faults, many of which are occupied by rhyolite dikes; other minor intrusions within the Twin Lakes batholith include irregular masses of fine-grained granite, and lamprophyric dikes.

The impact of a missile on water-saturated gypsum lake beds produced a crater about 30 feet across and 7 feet deep. A study by H. J. Moore and R. V. Lugn shows that the morphology and ejecta of the crater are similar to large natural craters produced by meteorite impact and some craters produced by explosives.

The stratigraphic sequence is overturned in the ejecta, the beds are locally folded near the crater rim, and there is some slumping of crater walls. Secondary impacts range from implanted fragments to craters containing fragments to craters not containing fragments.

The volume of this crater is about six times larger than one produced by a missile impact into dry alluvium, although the kinetic energies and angles of impact of the two missiles were nearly the same. The difference in size of the two craters is partly related to the difference in strength of dry and wet materials at elevated confining pressures because the strength of water-saturated materials is nearly constant, whereas the strength of dry materials increases. Hence, larger craters may be produced in wet targets than in dry ones by projectiles with the same kinetic energies and velocities. Calculations of the effective target strengths for the two craters using the Charters-Summers' theory of impact crater formation yield reasonable values for their deformation strengths.

H. J. Moore and D. E. Gault report the results of firing projectiles at 2-inch diameter spheres of basalt and large rectangular blocks of basalt and glass with planed surfaces. In addition, one basalt sphere was broken by compression. More large fragments and fewer small fragments are produced by high-velocity impacts into spheres than by impacts into large rectangular blocks. There is no clear correlation between the size distribution of debris from the spheres and the size distribution of meteoroids and meteorites. There are parallels as well as differences between the fragmentation produced by high-velocity impacts on spheres and spheres broken by compression. Breakage produced by impacts with the spheres is related to the kinetic energy of the projectile.

A study by C. H. Roach, S. P. Lassiter, and T. S. Sterrett of the meteorite craters at Odessa, Texas, shows that rocks to a depth of about 130 feet below the main crater have significantly lower concentrations of mercury than do stratigraphically equivalent rocks at a distance of 1.1 miles. The depletion of mercury in rocks at shallow depths beneath the crater may have resulted from processes caused by the impact event that formed the Odessa meteorite craters, or possibly by postimpact leaching by vadose waters percolating through the lens of brecciated rocks beneath the crater. Additional chemical studies are in progress to try to evaluate the reasons for the depletion or redistribution of mercury in the affected rocks.

The first systematic collection of meteorite material around Meteor Crater, Arizona, in which the location of each find was recorded and surveyed, has been completed by D. J. Milton and A. J. Swartz. About 90 specimens ranging in weight from a few grams up to 15 kg were collected.

Summary of Part C

Edward J. Dwornik illustrates the potential usefulness of the scanning electron microscope for investigations of materials of geologic interest by micrographs of several types of materials. The advantages of this scanning electron microscope over those of the optical microscope are the greater resolution (presently about 500A) and the large depth of field, allowing the direct examination of surface features of irregular objects. Compared to the transmission electron microscope, the resolving power of the scanning electron microscope is poor, and electron diffraction is not possible, but the depth of field is greater and sample preparation easier. For those problems in which morphology is important, as in the study of cosmic dust and in micropaleontology, the scanning electron microscope will be a useful tool in conjunction with a transmission electron microscope.

A fundamental problem in the origin of tektites is the estimation of the composition and nature of the parent material from which they were derived. Of equal importance is the nature and complexity of the system of processes that led to their formation. Some information relevant to these problems is thought to be contained in the estimates of correlation among various chemical constituents in tektite specimens. The observed correlations, however, are subject to restraints imposed on the data array by its numerical structure--in particular the constant item-sum and the forms of ratios and other functional variables of interest.

Data studied by A. T. Miesch, E. C. T. Chao, and Frank Cuttitta consist of chemical and spectrographic analyses as well as physical property measurements on 21 bediasites from east-central Texas. Correlation coefficients derived from these data were tested against correlations derived from <u>closed arrays</u> of random deviates. Many of the correlations that were apparently significant when tested against zero are no greater than can be attributed to the constant item-sum (closure) effect. Other correlation coefficients near zero are highly significant and indicative of petrogenetic association. Correlations involving either major or minor elements that have low relative deviations appear to be affected by closure to an important degree.

On adjustment of correlation coefficients for the possible effects of closure and the forms of functional variables, a measure is obtained that can be tested for significance against zero. This is used in factor analysis procedures that lead to a geologic model sufficient to account for the covariance relationships in the bediasite data. Three geologic factors are required in the model, and are tentatively regarded as (1) the amount of chondritic meteoritic matter incorporated into the principal parent material of the bediasites, (2) the degree of magmatic differentiation in the principal parent material, and (3) the effects of volatilization and other processes acting during tektite formation.

Donald B. Tatlock reports that bediasites, indochinites (including thailandites), and austral-philippinites (including javanites), owing to their wide range in (1) Al_2O_3 - (CaO + Na_2O + K_2O), (2) (FM)O, and (3) CaO, while (4) maintaining a narrow range in alkali ratio, are effectively separated on a modified ACF plot into strikingly similar grouping patterns. Each grouping pattern consists of a normal, a high FM, and a low alumina group. Among the Australasian tektites, the petrochemical groupings parallel the distinct compositional populations found in various areas of Australasia.

The normal groups, which probably constitute most of the tektite material on earth, are marked by low standard deviations of all major constituents, and they display significant negative correlation between excess alumina (normative corundum) and the ratio of alkali to (FM)O, suggesting there has been volatilization of the alkalis.

Significant correlations and ratios, common to both tektites and unaltered igneous rocks, are discussed. These, as a group, are not characteristic of sedimentary units. Bediasites and Australasian tektites are probably derived, by impact fusion differentiation, from lunar source materials of rather narrow compositional range, similar chemically to terrestrial hypersthene-bearing salic igneous rocks of Nockolds.

Emission spectrographic analyses of whole rock meteorite samples and separated plagioclase and pyroxene from basaltic meteorites reported by Michael B. Duke show variations consistent with a magmatic differentiation origin for those meteorites. Elemental fractionations between pyroxene and plagioclase are similar to those observed in terrestrial basaltic rocks. Certain compositional properties of the parent material of the basaltic meteorites, for instance that the parent material had a U-K ratio very close to that suggested for the Earth's mantle, are inferred from the data. Minor-element data for pyroxenes from hypersthene achondrites show similarities to those of basaltic meteorite pyroxenes, whereas a diopside achondrite and the Sherghotty basaltic achondrite are different, especially in their contents of siderophile elements.

Cohenite is found almost exclusively in meteorites containing from 6 to 8 wt. percent nickel. On the basis of phase diagrams and kinetic data, Robin Brett proposes that cohenite which formed in meteorites with a nickel content lower than 6 wt. percent decomposed during cooling, and cohenite cannot form in meteorites with more than 8 wt. percent nickel.

A series of isothermal sections between 750° and 600° C have been constructed for the system Fe-Ni-C on the basis of published information from the three constituent binary systems. The diagrams suggest that the presence of a few tenths of a percent carbon in a nickel-iron alloy may reduce the temperature at which kamacite separates from taenite by more than 50° C. Hence the presence of carbon in iron meteorites may be partly responsible for the supercooled nucleation of kamacite in meteorites required by recent authors. Meteoritic cohenite may form over the temperature range 650° to 600° C. For compositions approximating those of metallic meteorites, the greater the carbon or the nickel content of the alloy, the lower the temperature of formation of cohenite.

The presence of cohenite indicates neither high nor low pressures of formation in meteorites which contain it. However, the absence of cohenite in meteorites containing the assemblage metal + graphite requires low pressures during cooling.

M. B. Duke and M. H. Carr have begun work to determine the characteristics of cosmic dust. As a preliminary step they have been examining particulate matter collected at high altitude within the atmosphere and also are participating in experiments designed to collect cosmic dust above the atmosphere. The size distribution of cosmic dust is such that only very small particles can be collected. This has necessitated the establishment of analytical facilities specifically designed for the handling of small particles. Ultraclean laboratories have therefore been built in Washington and Menlo Park. Also the electron microscope and electron microprobe facilities in Washington have been upgraded, and similar equipment is being installed in Menlo Park.